Chaotic and Random Responses of Ocean Structures: Analysis of Medium-Scale Experiment

Solomon C.S. Yim
Ocean Engineering Program
Department of Civil, Construction and Environmental Engineering
Apperson Hall 202
Oregon State University
Corvallis, OR 97331-2302
phone: (541) 737-6894 fax: (541) 737-3052 e-mail: yims@ose.orst.edu
Award #: N00014-92-J1221 & N00014-97-1-0581 (AASERT)

LONG-TERM GOAL

The long-term goal of the research is to develop a unified, systematic, reliability-based analysis and design methodology for nonlinear, dynamically sensitive ocean structural systems incorporating the influence of a full range of possible motions. The transition phenomena among various complex nonlinear motions including periodic, quasi-periodic, chaotic, noisy periodic, noisy chaotic and purely random responses, and their effects on extreme excursions and fatigue behavior of structural systems will be emphasized.

OBJECTIVES

The immediate objectives are: (1) to analyze the measured data of a medium-scale experiment conducted at the OSU Wave Research Laboratory on the dynamic responses of a nonlinear moored system; (2) to calibrate the predictive capabilities of the analytical models developed under this research project using the experimental results; and (3) to study the transition phenomena among various types of response motions via the parameter maps constructed from the experimental results complemented with analytical predictions.

APPROACH

The approach is to first focus on the analysis of the measured stochastic responses of the single-degree-of-freedom (SDOF) system using nonlinear system identification techniques developed earlier in this project to identify the ranges of the system parameters. Individual deterministic test results will then be examined to further pinpoint the system parameters. Experimental data from the continuous scan runs will then be analyzed to construct the nonlinear frequency-amplitude primary and secondary resonance response curves. The resulting nonlinear map will then be calibrated against analytical predictions using the system parameters identified earlier. Numerical results will be generated as needed to complete the frequency-amplitude parametric map to fully delineate the nonlinear system response behavior. A parallel systematic analysis will also be conducted on the multi-degree-of-freedom (MDOF) nonlinear system to determine the coupling effects among various motions. Numerical predictions from efficient stochastic algorithms developed earlier for time and probability domain analyses will be calibrated using experimental results.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Chaotic and Random Responses of Ocean Structures: Analysis of Medium-Scale Experiment**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,Department of Civil, Construction and Environmental Emgineering,Corvallis,OR,97331**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

WORK COMPLETED

Selected SDOF and MDOF moored and free-floating system analytical models of physical structures corresponding to available experimental data from OSU and NFESC have been developed and examined [1, 2]. Numerical simulations and parametric studies of the deterministic and stochastic responses of these analytical models have been conducted. System parameters including added mass and damping coefficients have been identified for the moored-buoy and ship-roll models based on time-history and statistical comparisons of simulation data with preliminary experimental analysis results [3-5]. Transitions of nonlinear primary and secondary resonance responses of the SDOF model of the moored structures under narrow-band random excitations have been examined. Semi-analytical models of several transition routes and corresponding transition probabilities have been developed [6]. Data of the submerged moored-buoy system experiment for the SDOF surge-motion case have been analyzed. Stability regions of various nonlinear responses have been classified and estimated. Perturbation-induced transitions among coexisting characteristic responses have been identified and examined. Comparisons with analytical predictions are being conducted.

RESULTS

Semi-analytical probability models have been derived to describe inter- and intra-domain transitions in trajectories of the responses of the nonlinear system subjected to narrow-band excitations near the primary and secondary resonance regions [6]. The resulting predictions agree well with the corresponding time domain simulations. Comparisons of the analytical predictions and experimental results are being conducted.

Deterministic analytical and numerical predictions of resonance, sub-harmonic and super-harmonic responses [7, 8] produced by employed parameters obtained from the preliminary system identification procedures have been compared to experimental data (e.g., see Figure 1). The numerical results are found to be in reasonable agreement in general with experimental observation [9, 10]. It is anticipated that better agreements may be achieved when more sophisticated system identification procedures are developed to pinpoint the parameters of the systems in the sensitive response regions.

For the deterministic test runs, frequency response diagrams reflect nonlinear relationships between wave excitations and system responses of the moored buoy experiment. Stability regions of primary and secondary resonance in the diagrams are estimated (dashed lines in Figure 2). Near the stability boundaries, bifurcations and coexisting response attractors are observed. Note that circles corresponding to the same excitation frequency in Figure 2 indicate various response amplitudes under identical excitation parameters. Sudden changes of response amplitude in the time histories are observed in the experiment (e.g., transition from small to large amplitude in Figure 3). This transition phenomenon is caused by two factors, namely, the presence of a weak tank noise and the coexistence of multiple steady-state responses. Identification techniques are being employed to estimate the system parameters to fine-tune the investigation of the (co) existence of higher order nonlinear responses, including sub-harmonic, ultra-harmonic, quasi-periodic and chaotic ones. The basis and implication of orderly, timed transitions between coexisting multiple attractors of different response amplitudes of the surge motion of the moored-buoy system of deterministic test runs are being investigated.

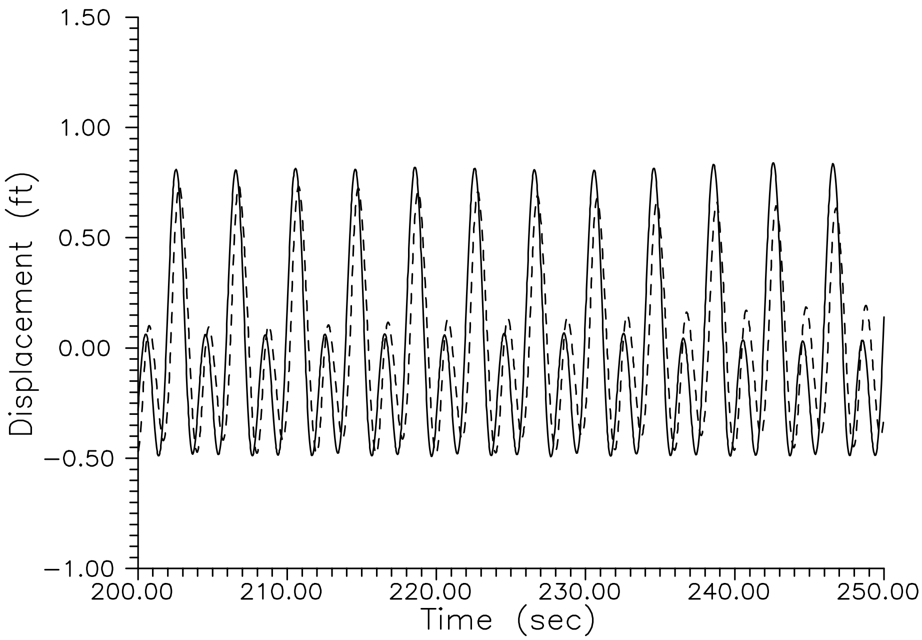

Fig.1: Comparison of experimental result (solid line) with numerical simulation (dashed line)

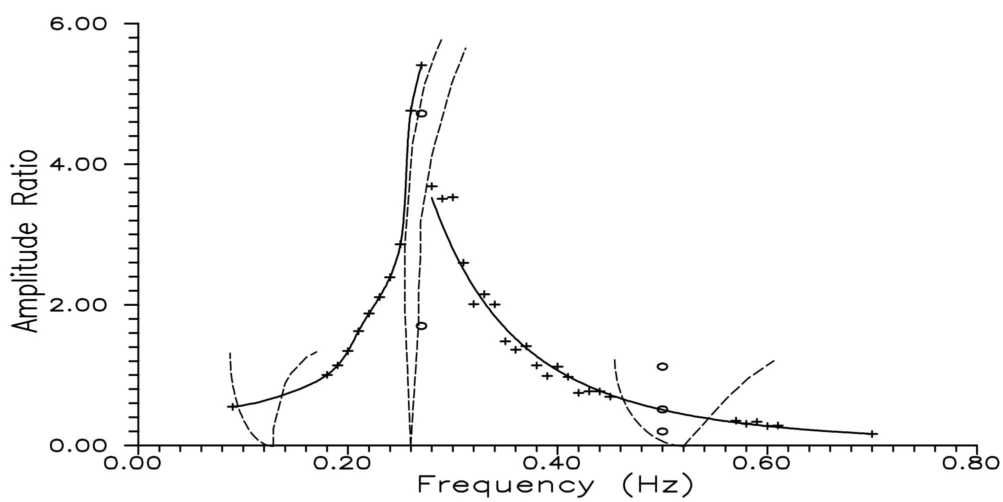

Fig.2: Frequency response diagram (experimental results); ---- estimated stability boundaries

For stochastic experimental test runs, random perturbations are found to bridge coexisting response domains. Combined response characteristics are observed in a typical response time history (e.g., Figure 4). Excitation perturbations in the experiment are categorized as additive band-limited noise and slow variations in amplitude and frequency (narrow-band). Effects on response characteristics due to each type of perturbation and their differences are being examined. Comparisons of analytical predictions [8, 10] and experimental results in the perturbation-induced intricate transition behaviors (inter- and intra-domains) are being examined.

A precursory examination of the complex, possibly chaotic, nonlinear responses on a limited number of cases also indicate reasonable agreement between numerical predictions and corresponding experimental results. Detailed comparisons of the analytical and numerical predictions and experimental results using a variety of geometric and numerical techniques will be conducted later in this research.

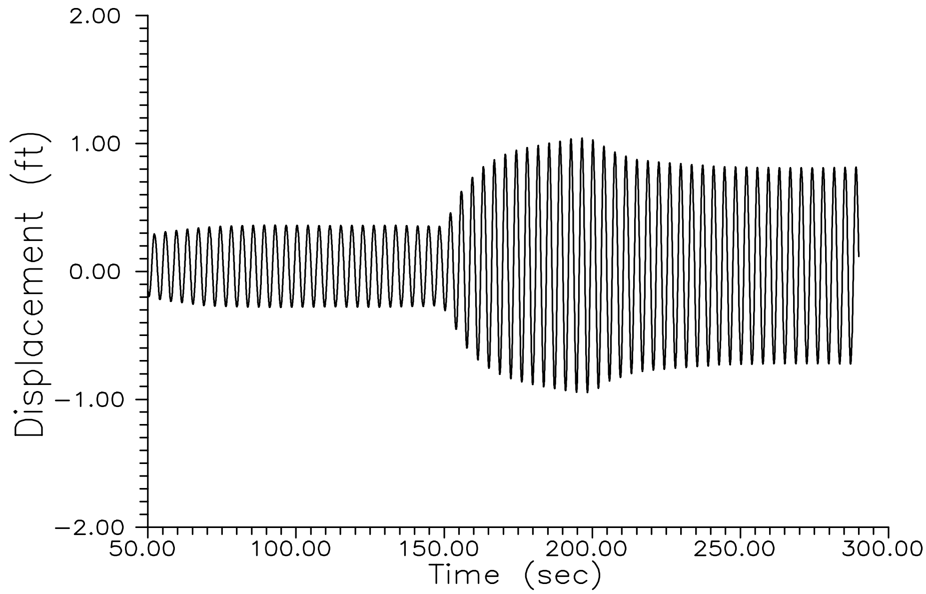

Fig.3: Transition from small amplitude response to the coexisting large amplitude

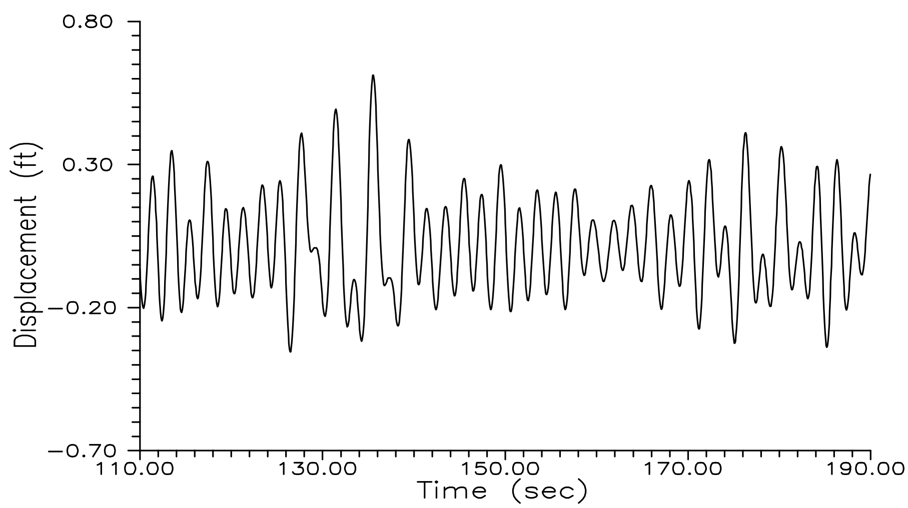

Fig.4: Perturbation-induced interactions between coexisting harmonic and sub-harmonic responses

IMPACT/APPLICATIONS

The nonlinear response superstructure [8] together with the timed nature of the transitions shown above, if found to be an invariant (deterministic or stochastic) feature of the complex responses, would give hope that reliable extreme value and cumulative fatigue predictions of these responses may be possible. Completion of the analysis of the SDOF and MDOF experimental data may provide sufficient information for the development of a unified analytical procedure to predict the long-term extreme value distributions and fatigue failure probabilities for the design of nonlinear, dynamically sensitive ocean structural systems.

TRANSITIONS

Some techniques developed in this research project have been found useful, and others are being applied in other disciplines. Specifically, the stochastic analysis techniques in the probability and time domains have been applied by contractors of NFESC (Port Hueneme) to analyze the nonlinear stability and capsizing probability of Naval transport barges.

RELATED PROJECTS

This research project complements those supported by other ONR programs on the study of physical systems and/or reliability of nonlinear ocean structures and hydrodynamics. There are significant cross fertilization of ideas and development/implementation of numerical techniques on nonlinear stochastic and chaos analyses between this project and those under hydrodynamics, mathematical sciences, physics and other programs. This research may eventually benefit higher category programs when the resulting unified analysis methodology can be employed in the design of Naval ships, barges, platforms and other special structures.

REFERENCES

1. S.C.S. Yim, W.A. Bartel, H. Lin, and E.T. Huang, 1995: "Nonlinear Roll Motion and Capsizing of Vessels in Random Seas," Report to Amphibian Division, Naval Facilities Engineering Service Center, Port Hueneme, May.
2. O. Gottlieb and S.C.S. Yim, 1997: "Nonlinear Dynamics of a Coupled Surge-Heave Small-Body Ocean Mooring Systems," *International Journal of Ocean Engineering,* Vol.24, No.5, pp.479-495.
3. O. Gottlieb, M. Feldman and S.C.S. Yim, 1996: "Parameter Identification of Nonlinear Ocean Mooring Systems Using the Hilbert Transform," *Offshore Mechanics and Arctic Engineering*, ASME, Vol.118, No.1, pp.29-36.
4. W.A. Bartel, S.C.S. Yim, and E.T. Huang, 1996: "Modeling, Validation and Simulation of Multi-Degree-of-Freedom Nonlinear Stochastic Barge Motions," Naval Facilities Engineering Service Center Report, June.
5. S. Narayanan, S.C.S. Yim and P.A. Palo, 1998: "Nonlinear System Identification of a Moored Structural Systems," Proceedings of the Eighth International Offshore and Polar Engineering Conference, Montreal, Canada, 24-29 May, Vol. III, pp.478-484.
6. I-M. Shih and S.C.S. Yim, 1998: "Stochastic Analysis of Complex Nonlinear System Response Under Narrow-Band Excitations," Ocean Engineering Report, Oregon State University, June.
7. H. Lin and S.C.S. Yim. 1997: "Noisy Nonlinear Motions of a Moored System, Part I: Analysis and Simulations," *Journal of Waterway, Port, Coastal and Ocean Engineering,* ASCE, Vol. 123, No.5, pp.287-295.
8. O. Gottlieb, S.C.S. Yim and H. Lin, 1997: "Analysis of Bifurcation Superstructure of a Nonlinear Ocean System," *Journal Engineering Mechanics*, ASCE, Vol.123, No.11, pp.1180-1187.
9. S.C.S. Yim, and H. Lin 1998: "An Experimental Calibration of Bifurcation Superstructure of Nonlinear Moored Structural Responses," *Journal Engineering Mechanics,* ASCE, Vol. 124, pp.471-475.

10. H. Lin, S.C.S. Yim and O. Gottlieb, 1998: "Experimental Investigation of Response Stability and Transition Behavior of a Nonlinear Ocean Structural System," *International Journal of Ocean Engineering*, Vol. 25 4/5, pp.323-343.

PUBLICATIONS

Yim, S.C.S. and H. Lin, 1998: "A Methodology for Analysis and Design of Sensitive Nonlinear Ocean Systems," Chapter 4, *Stochastically Excited Nonlinear Ocean Structures*, edited by M. Shlesinger and T.F. Swean, World Scientific Publisher, pp.105-128.

Idris, K., J.W. Leonard, and S.C.S. Yim, 1997: "Coupled Dynamics of Tethered Buoy Systems," *International Journal of Ocean Engineering*, Vol.24, No.5, pp.445-464.

Gottlieb O. and S.C.S. Yim, 1997: "Nonlinear Dynamics of a Coupled Surge-Heave Small-Body Ocean Mooring Systems," *International Journal of Ocean Engineering*, Vol.24, No.5, pp. 479-495.

Lin, H. and S.C.S. Yim, 1997: "Noisy Nonlinear Motions of a Moored System, Part I: Analysis and Simulations," *Journal of Waterway, Port, Coastal and Ocean Engineering*, ASCE, Vol.123, No.5, pp.287-295.

Gottlieb, O., S.C.S. Yim and H. Lin, 1997: "Analysis of Bifurcation Superstructure of Nonlinear Ocean System," *Journal of Engineering Mechanics, ASCE*, Vol.123, No.11, pp.1180-1187.

Lin, H., S.C.S. Yim and O. Gottlieb, 1998: "Experimental Investigation of Response Stability and Transition Behavior of a Nonlinear Ocean Structural System," *International Journal of Ocean Engineering*, Vol. 25, No.4-5, pp.323-343.

Lin, H. and S.C.S. Yim, 1998: "Experimental Calibration of Bifurcation Superstructure of Nonlinear System," *Journal of Engineering Mechanics, ASCE*, Vol.124, No.4, pp.471-475.

Leonard, J.W., K. Idris, and S.C.S. Yim, "Large Angular Motions of Tethered Surface Buoys," *International Journal of Ocean Engineering*, to appear.

King, P.E., and S.C.S. Yim, "Control of Nonlinear Rocking Responses of Free-Standing Rigid Blocks," *Journal of Engineering Mechanics, ASCE*, submitted.

Yim, S.C.S. and H. Lin, "Noisy Nonlinear Motions of a Moored System, II: Experimental Comparisons," *Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE*, submitted.

Narayanan, S., S.C.S. Yim and P.A. Palo, 1998: "Nonlinear System Identification of a Moored Structural Systems," Proceedings of the Eighth International Offshore and Polar Engineering Conference, Montreal, Canada, 24-29 May, Vol. III, pp.478-484.

Lin, H. and S.C.S. Yim, 1998: "Experimental Investigation of Stability and Bifurcation of Nonlinear Moored Structural Responses," Proceedings of the Eighth International Offshore and Polar Engineering Conference, Montreal, Canada, 24-29 May, Vol. III, pp.485-489.

King, P.E. and S.C.S. Yim, 1998: “Active Control of Noisy Nonlinear Oscillations in a Structural System,” Proceedings of the Second World Conference on Structural Control, Kyoto, Japan, 28 June - 1 July, in press.

Lin, H. and S.C.S. Yim, 1998: “Stochastic Melnikov Analysis of Rocking Responses to Noisy Periodic Excitations,” Fourth International Conference on Stochastic Structural Dynamics, Notre Dame, IN, 6-8 August, in press.

Lin, H. and S.C.S. Yim, 1998: “Reliability Analysis of Rocking Responses to Random Excitations,” Fourth International Conference on Stochastic Structural Dynamics, Notre Dame, IN, 6-8 August, in press.

King, P.E. and S.C.S. Yim, 1999: “Periodic Dynamic Responses of a Controlled Ocean System,” Proceedings of the Ninth International Offshore and Polar Engineering Conference, Brest, France, submitted.